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Conceptualizing Pharmaceutical Plants

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Abstract: In the conceptual design phase of pharmaceutical plants as much as 80%-90% of the total cost of a project is committed. It is therefore essential that the chosen concept is viable. In this design process configuration and 3D models can help validate the decisions made. Designing 3D models is a complex task and requires skilled users. We demonstrate that a simple 2D/3D configuration tool can support conceptualizing of pharmaceutical plants. Present paper reports on preliminary results from a full scale implementation project at a Danish engineering company.

Key words:
3D;2D;configuration;conceptualizing;usability.

1- Introduction

The proverb ”A picture says more than a thousand words” is often used to describe the essence of visualization. If the visualization of the product is carried out correctly, the user should be able to take advantage of his perceptual skills to make sense of the complexity of the product and reduce load on higher cognitive skills, which are serial and slower. Hence, the visualization aids the user to see underlying patterns and understand relationships between components in a complex product and thereby aids the user to configure the product.

In recent years the visualization of products through geometric oriented product models such as CAD-systems has become an integrated part of the business processes in manufacturing enterprises. In the field of mechanical engineering CAD-systems are the leading software for product visualization. The intense developments made in relation to geometric product models such as CAD systems have not resulted in a higher degree of integration between geometric product models and knowledge-based product models such as configuration systems. As for the configuration systems that exist on the market today, they are primarily rooted in knowledge-based product models without possibilities for interaction with the visualization of the product.

Present paper concerns development of a visual configuration system for conceptualizing plants and products and not visualization in other situations, such as product development and product design. The case in focus of this paper is support of the conceptual design process by application of advanced 2D/3D modeling to create multiple scenarios and thus strengthen the decision process. Designing a 3D model is a complex task. Common tools for creating 3D models in the industry are CAD applications such as AutoCAD, Solid Works etc. In the movie and game industry the common applications are 3D Studio Max, Maya and Softimage.

Usually it takes years to master a 3D modeling package. Users often become experts in a specific 3D modeling tool and if they start using a different 3D modeling tool it again requires substantial time to master the slightly different methods used in that application.

The 'tool' that is presented in present paper have the characteristics of both being a configuration system, presenting prices, bill-of-materials, and ensuring reuse of knowledge, as well as a 3D modeling tool creating a conceptual 3D model of pharmaceutical plants. The tool was developed to enable ordinary employees to create a detailed 3D model of pharmaceutical plants.

1.1- Structure of Paper

The paper starts out with establishing of user needs in relation to the conceptualization of plants in NNE. This is followed by a brief description of possible solutions. Next the implementation of the 'tool' is described with the workflow in focus. Finally results and experiences from operation of the tool is discussed and concluded.

1.2- Previous Work

The area of product configuration and product modelling has been actively researched [H1; H2; S1; SS1], but the scope of most of the work done has been very limited and specialized. Likewise, the area of integrating knowledge based product models with product visualization has not been as actively researched. Experience from research on product modelling at Centre for Product Modelling pointed out the need for research on the benefits of visual validation of the product in relation to product configuration. Hence, a need exists for more specific knowledge on how complex products are configured with dynamic visualization and interaction.

2- Case: NNE

With more than 80 years of experience, the engineering company NNE is a leading supplier of systems, consultancy and engineering services to the international pharmaceutical and biotechnological industry. NNE's competencies span all technical disciplines applying to engineering, construction, validation, start-up and optimization, and reconstruction of facilities for product development and production plants, pilot plants and laboratories within the pharmaceutical and biotechnological field.

NNE executes projects by applying modular engineering principles. By breaking a plant down into modules that can be constructed and tested off-site, NNE gets around some of the time-related constraints arising at a construction site. These constraints can be site conditions, qualified building resources, problems with conducting several tests at one time as a result of inadequate supplies, test personnel or QA resources, organizational and logistics related complexity at the construction site. The main elements in modular engineering are:

- Modular process design that addresses all project phases and validation and operation of the plant
- Modular building engineering using intensive and flexible off-site construction resources
- A set of project execution tools supporting the fast track engineering activities and using modular principles adapted to the specific project.

With the use of fast track engineering and modular principles, NNE is in a position to construct a pharmaceutical plant in record time.

2.1- Conceptualizing Pharmaceutical Plants

In recent years productivity has been an important issue in the pharmaceutical engineering industry, and especially the Latham report addresses this issue [L1]. According to Abdul-Kamir and Price [AP1], attention has so far primarily been focused on the phases following conceptual phase of construction projects even though the conceptual phase is of strategic importance in the project environment. Hence, understanding and improving this phase is a prerequisite for improving productivity on site and reducing the construction costs and schedule.

The conceptual phase has a significant influence on the course of the phases to come, because it commits a lot of the cost to come in the later phases. Often as much as 80%-90 % of the total cost of a project is committed already in the conceptual design, see [AP1]

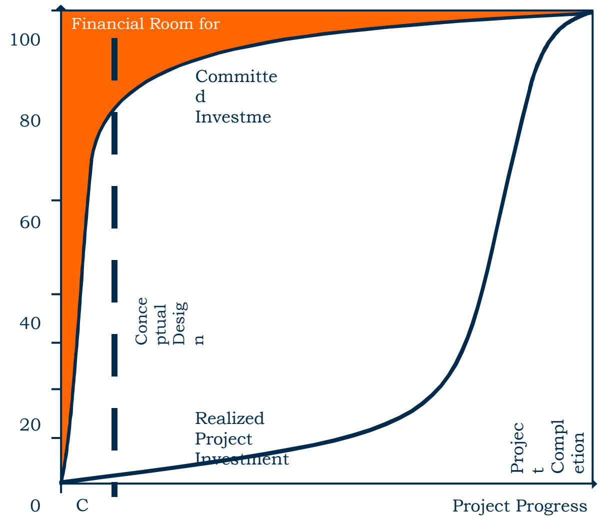

Figure 1: Committed investment vs. realized investment

Thus, the success of the phases to come very much depends on the decisions made in the conceptual phase AP1]. The conceptualizing of plants is therefore extremely important, and this is stressed by the fact that the chosen concept of the project in fact commits a lot of the total costs of the project. The key activities in the conceptualizing phase in the pharmaceutical engineering industry are:

- Product capacity
- Area need & area concepts
- Process and utility concept
- Layout principles

Through these activities a proposal containing the concept for the plant is delivered to the customer. To deliver viable conceptual solutions and at low costs is a key competitive factor, and to reach this the following factors are important:

- Reuse of existing knowledge
- Minimizing # of errors
- The customer should be presented to alternative solutions, to allow the customer to choose the preferred solution
- Communication across boundaries (internally as well as externally)
- The process should give the customer an impression of the engineering companies being both flexible

and dynamic

- The process should support that the customer gets influence on the tasks that are to be done during the Conceptual Design phase (or at least gets an opportunity to this)

The aim of the conceptualizing tool is to support the following decisions that are hard to communicate to the customer.

- Area needs for various equipment,
- site evaluation and expansion typologies,
- plant layouts, and
- flow of materials and personnel.

The focus of the project is to stimulate cross disciplinary collaboration through visualizing equipment and building modules. At the same time it was a condition that the systems facilitated reuse of knowledge.

2.2- User needs in conceptualizing of plants

To establish a common understanding of which needs the user has for tools to support conceptualizing of plants a series of interviews at NNE (a Danish engineering company) have been carried out. The interviewees all come from different backgrounds (architecture, mechanical engineering, chemical engineering, process engineering), and common for all of them is, that they work in the conceptual design department of NNE. The employees in the conceptual design department are responsible for making conceptual designs for all projects in NNE ranging from reconstructions to Greenfield projects.

One of the primary objectives of the conceptual phase is to describe process, material, and personnel flow. In this process a detailed description of the process is necessary and a conceptualization of the area need and concepts. An important task in the conceptualizing phase is to optimize the sqm used in the project. To do this area concepts are made estimating how many sqm should be used to a given process area taking material and personnel flow into consideration. While this seems like an easy task lots of scenarios for area concepts are often made involving almost all disciplines – from architects to mechanical engineers. Often the communication is troubled by the lack of common visual models for the area concept and a lack of common understanding of drawings concepts, etc, not making it clear for all disciplines which challenges are necessary to focus on. 3D models could help in evaluating the different area concept against each other.

The primary need was hence to be able to communicate knowledge and the background information for their decision to the customer as well as other disciplines involved, e.g. why the decision is made to use 20sqm extra in the fermentation area. Often this decision can seem illogical based on a 2d drawing of process equipment, but taking material and personnel flow in consideration the decision seems completely logical. This is often hard to communicate to the customer, and especially a customer looking for every opportunity to squeeze every area thus seemingly minimizing costs. It was the general perception that a visualization of the scenario could help the user in seeing the drawbacks of such a squeeze.

A solution to this issue has been to involve CAD experts in the early conceptualizing phase to make drawings to help evaluate area concepts. However there are often not time nor money to make drawings of different scenarios, and as side effect it was discovered that drawing only one scenario had the unwanted effect that it often limited the involver's perception to the specific drawn scenario. Another problem was the fact that when the CAD expert first had begun modeling the solution he was unable to incorporate scope changes quickly.

The conclusion was that there existed a need for a sketch like 3d modeling tool – a tool that were as easy to sketch in as Microsoft Visio [http://office.microsoft.com/visio/] (in 2d) and could deliver a conceptual 3d model for use in cross disciplinary communication as well as in proposal material to the customer. By using the tool it should be easy to make sketch like 3D scenarios containing process equipment as well building details.

It was concluded that often there was not correlation between what the customers thought they was getting and what they actually got - meaning that the communication of the proposed concept was poor. It is of high importance that drawbacks and benefits of the chosen concept is visually communicated. This is hard to do on basis of a 2D sketch and easier with a browse-able 3D model.

Finally it is important that the conceptualizing tool is able to deliver outputs to other systems, so the work laid in the conceptual model are not lost in relation to work in other tools.

2.3-Solutions

Many solutions exist to the goals described in the previous section. We will only evaluate a subset of the most popular ones. We will evaluate the following tools for conceptualizing proposals for plants in the following sections:

- 2D - Sketch
- 3D - CAD
- Text-Based Configuration
- Physical Models

2.3.1- 2D - Sketch

The first 2D design program is considered to be sketchpad [S2] which was developed by Ivan Sutherland as part of his ph.d. thesis. It was a revolutionary program and is considered to be an ancestor of modern computer-aided drafting (CAD) programs. Sketchpad was even slightly object oriented and it contained of a number of 2D objects that could be instantiated. The same principle is used in many 2D design programs today although more advanced. It is well known that sketching is a good tool for prototyping a conceptual design [L2]. Currently, Microsoft Visio is a tool that is often used in the conceptual design phase for sketching.

Microsoft Visio and other tools like it have a number of advantages. It is a very easy and user friendly tool that among other things can be used to visualize a floor layout in 2D. For this reason it is has found a place in the standard tool box of many conceptual design engineers.

Nevertheless, such 2D programs also have a number of disadvantages. First of all there is no easy method for converting a Microsoft Visio 2D floor layout to 3D. Furthermore, it is not possible to establish complex rules between objects, and finally it is not possible to create objects that can be configured in order to reuse knowledge.

2.3.2- 3D - CAD

CAD has been the predominant tool in mechanical engineering for many years. While it delivers unmatched performance in the detailed design of given products it has some limitations in the conceptualizing phase. An industrial designer relating to an existing CAD system is quoted saying "The interface is just not for us. I can do thirty sketches on paper by the time it takes me to do two on the computer" [J1].

CAD is an accurate 3D modeling tool and by using CAD it is possible to create a fully detailed model which afterward can be created physically using only the specifications in this 3D model. This is often done by extracting and printing a number of drawings. Detailed 3D models also make it possible to create photorealistic images of the model.

Creating an accurate 3D model is a requirement when constructing the final building but in the conceptual phase it has some drawbacks. First of all it is not necessary to have very accurate 3D models in this phase as the 3D models are often only used to communicate the concepts in the project.

Creating a 3D CAD drawing also requires highly skilled users and usually it takes years to completely master a specific CAD application. The personal involved in the conceptual phase are rarely familiar with CAD applications. When creating a CAD model it is hence necessary with additional personal dedicated to the task of creating a CAD model.

The creation of detailed 3D CAD models is a very time consuming task and even skilled CAD users demand substantial time for creating 3D models. In the conceptual phase it is often necessary to create multiple scenarios which mean that several 3D models must be created. This is of course even more time consuming. Additionally, the scope often changes which require small or even major changes to the 3D model.

2.3.3- Text-Based Configuration

A text-based configurator usally consists of a number of rules and constraints. These can be defined using many different methods e.g: Boolean logic, scripts, tables etc. [R1]. A vast number of commercial systems for creating such rules exist. [http://www.arraytechnology.com, http://www.oracle.com/, http://www.configit-software.com]. Each of these systems support one or several of the rule types.

In a text-based configurator everything has to be described explicitly and the solution space is finite. Often the configuration process is made op by a series of steps guiding the user through a series of screenshots. In most text-based configuration systems it is not possible to deviate from these predefined steps, making it hard for the user to adapt the use of the configurator to a situation where the predefined logical steps are not applicable. One advantage of using a text configurator is that when the knowledge has been entered into the system it is easy to access this knowledge and users of this configurator are instantly made experts. Another advantage of this approach is that only valid solution can be configured. This is a very important property for configurations that will be created directly from the configurator (Configure to Order). Finally configuration systems facilitate reuse of knowledge, and constitute a fixing point for knowledge acquisition in the organisation.

But there are also a number of disadvantages to this approach. If the rules are based on properties that are hard to understand it may be hard to use the configurator for non-experts. If the configurator contains a high number of rules it may be complicated to maintain these rules and it may not even be worth the effort to create a configurator if the number of configurations made in the system is low compared to the effort it takes to create and maintain the rules.

Another issue with text-based configuration systems is that it is hard to create visualizations halfway through the configuration process. Often a completed configuration model is needed making visual validation on the run hard to achieve.

2.3.4- Physical Models

Physical models of a proposed solution have been used for many years. In architecture companies there is often dedicated persons that create miniature models of the buildings. Miniature models is also used in engineering companies but as the interesting part is often more the structure of the building rather that the visual impression it is also seen that Lego bricks are used for this purpose [http://www.lego.com].

It is clear that the advantage of a physical model is that it gives a good overview of the solution that is easy to communicate. Often the physical model is even easier to understand than photorealistic images.

A disadvantage of using physical model is that it is hard to modify the model when changes to the scope occur after the physical models have been built.

Recently new commercial tools have become available which are able to automatically print 3D models [http://www.dimensionprinting.com/] [http://ww.zcorp.com] [http://www.solid-scape.com/]. This makes it possible to automatically create a physical model. The printers are still quite slow, and it takes several hours to print a model.

Nevertheless, compared to creating the model by hand it is much easier and faster and does not require a person to supervise the process.

2.3.5- Evaluation

All the solutions above each have unique advantages, and often the approach in a project is to use several of these solutions. A disadvantage of using several approaches is that if the concept is changed all the solutions must be updated.

2.4- Chosen Solutions

Our initial approach was to start with a tool that should be similar in ease of use to Microsoft Visio and other 2D drawing applications. Microsoft Visio is a tool that many people in the conceptual design phase are already familiar with. The created conceptual design must also be viewable in 3D. Consequently, we want to let the 2D model correspond to a 3D model and in this way make it possible to work in 2D and instantly get a 3D model. Furthermore, when the 3D model is edited the 2D model should be updated correspondingly. The components will therefore both have 2D and a 3D visual representation. To facilitate reuse of knowledge we decided to implement configuration functionality. In order to put knowledge into the elements it is necessary to add properties. This could be both visual and non-visual properties. When changing the visual properties both the 2D and the 3D representation will change.

3- Presentation of the Developed Tool

Our focus was to create a good workflow and create an application that supported the tasks described in the previous sections. In the following section the functionality of the conceptualizing tool will be presented.

The first step in the process is often to change the layout of an existing building. To support this process we have made it possible to import existing 2D floor layouts in different formats (see figure 2 and figure 3). We have only added options for importing 2D floor layouts.

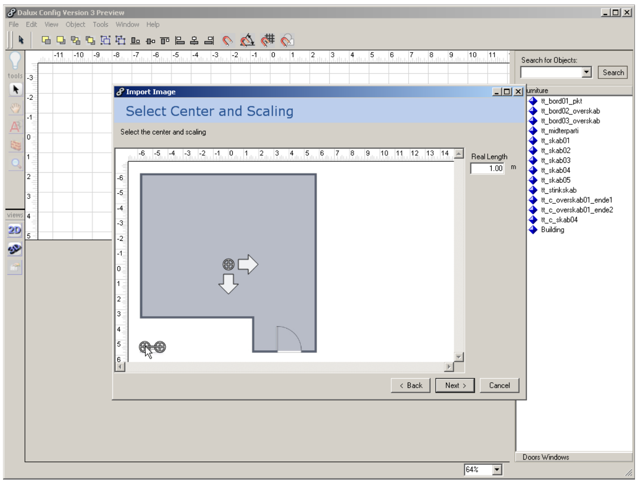

Figure 2: Importing existing 2D building layout

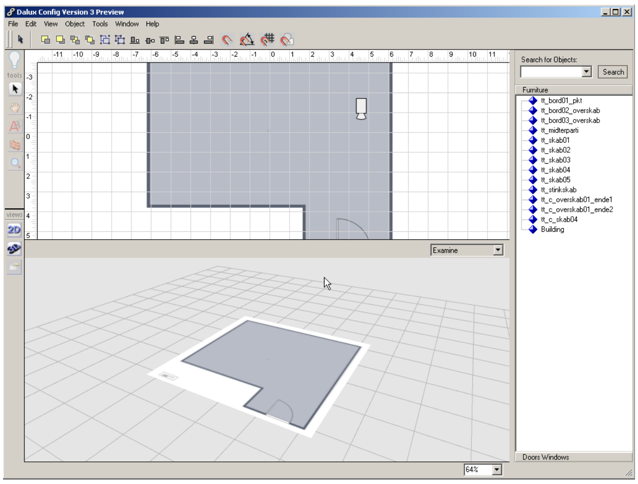

Figure 3: After importing existing 2D building layout

The next step will therefore be to create the walls in 3D based on this 2D image. We make this possible by using a wall tool and draw lines where the walls should be. The walls are then automatically raised. After the 3D wall structures has been created the needed equipment will be inserted. This is a creative process in which many different solutions can be tested.

Consequently this is the most important phase to make a good and easy to use user interface. As stated previously we have chosen to create a user interface that is in many ways similar to Microsoft Visio and other 2D drawing tools. We have added the possibility for viewing the model in both 2D and 3D at all times. Most of the interaction is done in the 2D view although it can just as well be carried out in the 3D view (see figure 4 and figure 5).

Many of the objects that are inserted is configured e.g. width, height, capacity etc. which changes the visual look and size of the object while also changing the prize. We use a number of different methods for the rules. The first method is a commercial logic kernel from array technologies [http://www.arraytechnology.com] which is used for making sure only valid products are chosen. Another method is Excel spreadsheets which are mostly used for calculating the prices based on the chosen configuration. The last method is .NET scripting which is used for advanced calculations. This is all stored in the product model inside the system.

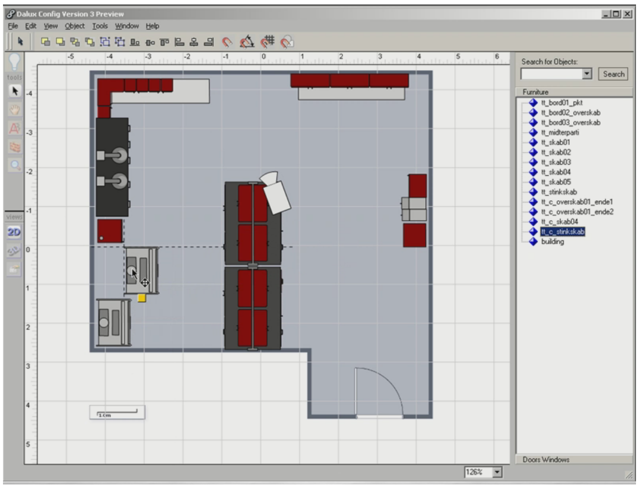

Figure 4: 2D interacting with the conceptualizing tool

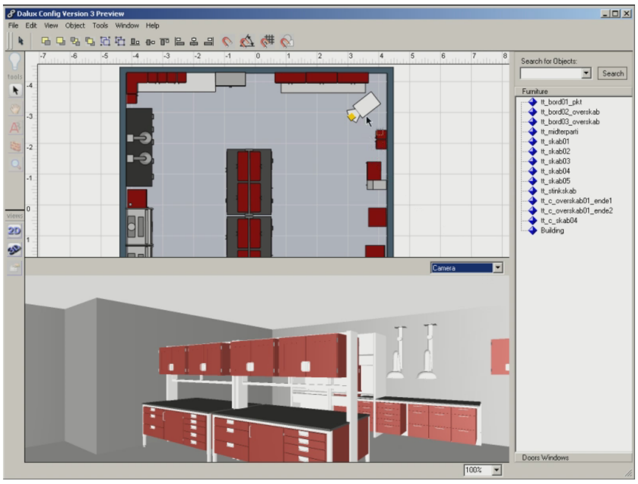

Figure 5: 2D/3D interacting with the conceptualizing tool

During the process several designs need to be evaluated. The design can be evaluated by looking at the 2D/3D views as shown in figure 4 and 5. We have also made a couple of other possibilities.

First of all it is interesting to see the price and list of objects needed for the chosen configuration (See figure 6).

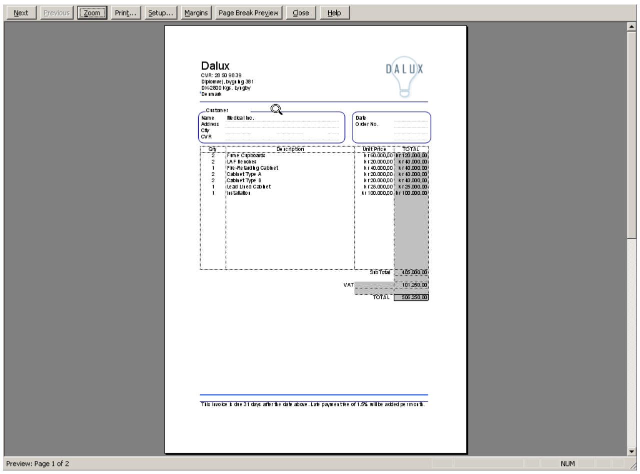

Figure 6: Price list generated by the configuration engine

The quality of the 3D images produced in real-time is lower than what is possible using a non-real-time renderer. A non-real-time renderer can use several hours to create a single image, but the quality of this image is also substantially better than real-time images. We have therefore added an option to the program so that the 3D model can be sent to a render server located on another PC that creates a high quality image of the 3D model based on the current view on the model.

After a while the final image is send back to the user using simple email (see figure 7 & 8). We use a separate PC for this purpose because creating a high quality image requires much CPU power and would consequently stall the users PC for a long time.

Figure 7: High quality rendering of the 3D model

Figure 8: High quality rendering of the 3D model.

Another option we have added is to export the 3D model to a 3D printer that can print a physical model (see figure 9). We have used a printer from Z-Corp for this purpose as this is the currently the only 3D printer that can print using colors.

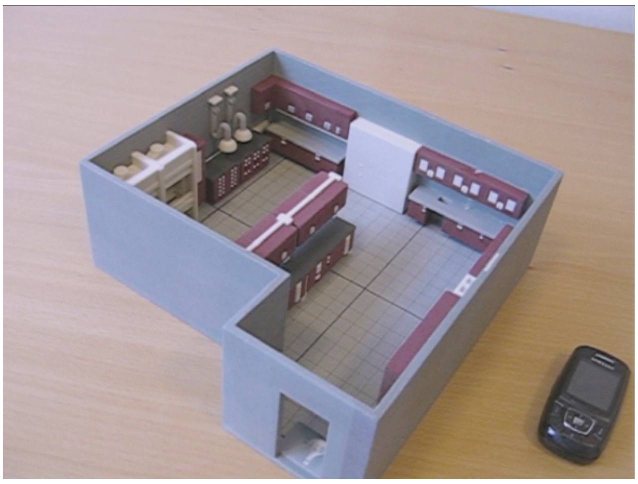

Figure 9: Physical 3D print and a mobile phone to show the size of the printed 3D model

When the final design has been determined the model can be exported to a CAD system and then the details are added and the work invested in the conceptual 3D model can be used in the phases to come.

4- Discussion

The preliminary experiences from the operation of the tool in the conceptual design phase indicate that the tool has benefited the conceptualizing process internally in NNE as well as externally in relation to customers.

The tool has been in operation at NNE since Jan 2006, and has been used in app. 15 conceptual designs of a varying size. It is hard to determine whether the concepts are better and more viable than before the use of conceptualizing tool. However one thing is for sure – the conceptualizing tool has both strengthened the relationship with the customer, and the inter-disciplinary work in NNE through:

- Visual Communication
- Easy Scenario Creation
- Reuse of Knowledge (Price and Modules)
- Correlation between equipment and building

Engineers and architects without any prior experiences with 3D modelling are now able to create 3D models to evaluate solutions and concepts in an easy and intuitive way. This has enabled the employees to model different scenarios and evaluating them against each other. The users are very satisfied with the tool and acknowledge one of the most important benefits in being able to communicate solutions and concepts with the customer through exchange of 3D models.

As an extra benefit, the text-based configuration embedded in the tool warns the users when creating invalid solutions but does not restrict the user from making invalid solutions. (e.g. notification about collision – but nothing stops one from making this illegal solution). This has facilitated reuse of knowledge in projects because formalized and validated knowledge is implemented in the conceptualizing tool and therefore available for all employees.

The highest cost driver of the project at NNE has been the time and money invested in the product model. To realize benefits related to reuse of knowledge a lot of work has been invested in the product model at NNE.

4.2- Discussion of Usability

As stated in a previous section one of our main goals was to create an easy to use interface. We have made it possible to interact in both 2D and 3D. It turns out that users prefer to design in 2D if it is possible and then only use 3D for inspection or minor modifications. Most of the time when designing a floor layout it is possible to do this in 2D. Working directly in 3D is often only needed when stairs and other objects that span several floors are used. But these few cases make it very important to work in 3D. Often it is hard to imagine the 3D layout from two 2D views. During our implementation process we have had a case where the design of 2 floors was finalized but when it was inserted into the system and viewed in 3D it turned out that the configuration did not leave room for entering the stairs. Such mistakes are extremely costly if they have to be corrected after the room has actually been build.

Our approach of using a standard windows interface turned out to be successful. Sometimes we came up with what we though was better solutions for a user interface than the standard windows user interface. But by using the standard windows user interface instead we were able to minimize the amount of time used for explaining how to use the program to the users.

5- Conclusion

The tool presented in this paper is used to conceptualize pharmaceutical plants. To identify requirements interviews was performed at NNE – a Danish provider of consultancy services to the pharmaceutical companies. Based on these requirements, and an evaluation of existing tools, a tool for aiding the conceptualizing phase was implemented and tested. Experiences from operation indicate that the tool strengthens both interdisciplinary work, and communication towards the customer regarding the conceptualizing of pharmaceutical plants. The tool enables ordinary employees to create advanced 3D models through an intuitive user interface utilizing a comprehensive product model that facilitates the reuse of knowledge..

As a future project we intend to create small guide applications and put knowledge of different processes into these guides. By activating these guides the system will automatically create or change the existing design according to system recommendations.

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